International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 9, Issue 2, Apr 2019, 111-122

"FEA ANALYSIS AND OPTIMIZATION OF TWO-WHEELER BIKE MONO SUSPENSION SYSTEM"

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ABSTRACT

Most of the Indian roads are pathetic in nature and 2 wheelers are the worst hit of this. So it is very essential to have a very good suspension system for the 2 wheeler to avoid accidents and improve the ride quality The modern motorcycle uses suspension to accomplish several things it provides a smooth comfortable ride absorbing bumps and imperfections in the road. This paper deals with analysis of mono suspension spring by using FE approach. Considering the highest level safety and ride control by shock waves and dissipated kinetic energy some concepts were built in mono shock absorbers and later they compared with the existing functioning systems adopted in the 2 wheeler. 3 concepts were developed where considering in starting helical spring alone and then hydraulic damping, gas damping systems were built to achieve the best 0.8 damping ratio for mono suspension system. Starting with single helical spring only suspension later advanced hydraulic with gas accumulator is studied in detail. Maximum damping value of 0.8 is achieved with combined spring, hydraulic and has accumulator design concept. Response curve is plotted against dynamic loads and three different loads 200 Kg, 250 Kg and 300 Kg is studied.

KEYWORDS: Mono Suspension, Dampers & Shock Absorber

Received: Jan 08, 2019; **Accepted:** Jan 28, 2019; **Published:** Feb 08, 2019; **Paper Id.:** IJMPERDAPR201911

Original Article

1. INTRODUCTION

The suspension system is the integral part of the vehicle. The purpose of the suspension system is to isolate the vehicle body from the irregular bad roads and maintain the contact of the wheel with the road. Efficient suspension system should provide the highest comfort to the rider with absorbing all the road disturbances. Today we can see the simple leaf spring suspension system to the complicated impendent algorithm suspension systems in the various types of vehicle. Depending on the vehicle and type of load it carries i.e. passengers; goods etc. suspension system will be designed.

An efficient suspension system should absorb road disturbances as well as load disturbances. Road disturbances include hill type large magnitude in low frequency and road roughness low magnitude of high frequency. Load disturbances include external loads, braking loads, turning loads, accelerating loads crash loads etc.

2-Wheeler suspension is an important category where comfort, ride quality, handling is decided by the suspension system. In India 2-wheeler market is growing in vertical direction and India has the highest population of the 2-wheelers. Indian roads are very bad in nature. Reliability of the vehicle, handling and ride comfort will be greatly decided by the suspension system. So a lot of research is going on to improve the suspension system of

2-wheeler.

2. ANALYTICAL TESTS

Analytical calculation is made for single helical spring system. The simplest mathematical model is constructed for the calculation and same will be adopted in FEA analysis. Here the commercially available Chrome Silicon Steel ASTM A410 is used as spring material.

This type of alloy steel for sprig is best suited for conditions which involve high stress and application like sudden shock. It contains Carbon 0.51-0.59%, Cr 0.60-0.80%, Si 1.20-1.60%. Details of the spring are tabulated here.

Table 1: Material Properties Cr Si ASTM A410

Modulus of Elasticity	207E3 MPa
Density	7850 Kg/m^3
Shear modulus	1160080 GPa
Minimum tensile strength	1620-2069 MPa
Rockwell Hardness	C48-55
Max Operating temperature	245^0 C
Max Allowable shear stress	900 MPa
FOS	1.5

Here the shock absorber oil (SAE grade 20w commercial) is used. Details of the properties are tabulated below.

Table 2: Hydraulic Oil Properties

Kinematic viscosity of the oil cSt @ 40^0 C	64
Kinematic viscosity of the oil cSt @ 100^0 C	8
Viscosity index min	110
Pour point ^{0} C max	-18
Flash point, COC, ^{0}C min	210
Appearance of the oil	Clear Light golden

Table 3: Dimensions of Single Helical Spring

Total length of the helical spring (max condition)	150 mm
Mean diameter of the spring	60 mm
Diameter of wire (Initial condition)	10 mm
No of turns	7
Pitch	18
Spring rate	5

For designing of the shock absorber concept load is considered as avarage weight of the bike and along with avarage weight of a single person with 3/4th of the rare weight which is taken as 200 Kg.

Hence the spring properties are choosen according to the above mentioned table and loading also considered as mentioned above for calculations.

Deflection of the spring = $\delta = \frac{8Wd^3n}{Gd^4}$

$$\delta = \frac{8 \text{ x } 200 \text{ x } 9.81 \text{ x } 60^3 \text{ x } 7}{85000 \text{ x } 10^4}$$

= 27.92 mm

Diameter of wired= 10 mm considered with max deflection allowed **id** 75 mm with full load.

Walhs stress factor =k $= \frac{4c-1}{4c-4} + \frac{0.615}{c}$

Spring index = C =$\frac{D}{d}$

C= 6

Walhs stress factor, k = 1.2525

Shear stress at the spring =$\tau = \frac{8FDk}{\pi d^3}$

$= \frac{8 \text{ x } 200 \text{ x } 9.81 \text{ x } 60 \text{ x } 1.2525}{\pi \text{x } 10^3}$

Shear Stress = 375.46 N/mm^2

Torque on spring =T $=$ Fx$\frac{D}{2}$

T = 58860 N-mm

Polar moment of inertia of wire, I =$\frac{\pi d^4}{32}$

I = 981.74 mm^4

Energy absorbed in the suspension system

$U = \frac{\tau^2}{4 \text{ x } k^2 \text{x } G} \text{x } (\pi \text{x D x n}) \text{x } (\frac{\pi \text{x } d^2}{4})$

U_1 = 1531.91 N-mm

Now load is considered as avarage weight of the bike and along with the avarage weight of two and three persons with 3/4th of the rare weight is considered as 250Kg and 300Kg respectively is tabulated below.

Table 4

For 250 Kg	
Deflection	34.91 mm
Shear stress	469.26 MPa
Torque	73575 N-mm
Energy absorbed in suspension	2397.7 N-mm

Table 5

For 300 Kg	
Deflection	41.88 mm
Shear stress	563.12 MPa
Torque	88290 N-mm
Energy absorbed in suspension	3452.99 N-mm

Dynamic Frequency Calculation:

Table 6: Dimensions of Single Helical Spring for Dynamic Frequency Calculation

Load	200 Kg
Stiffness K	71633 N/m
Gravity	9.81 m/s^2
Type of frequency	Harmonic in nature

Natural frequency of the suspension system = $W_n = \sqrt{\frac{k}{m}}$

= 18.92 rad/s

Frequency =f $= \frac{\omega}{2 \text{ x } \pi}$ = = 3.0112 Hz

Time Period = $\frac{1}{f}$ = 0.332 sec

Amplitude:

$Y(t) = U_0 \text{x} \cos \omega t + \frac{V_0}{\omega} \sin \omega t$

V_o= 0 Final displacement

= 0.02792 x cos (18.92 x 0.332) + (0)

= 27.75 mm

W_f = Natural frequency at vehicle speed

At 1 Km/Hr speed

W_f= 1.745 rad/s

At 5 Km/hr speed and at road amplitude 50 mm

W_f= 5*1.745 rad/sec= 8.725 rad/sec

Amplitude Ratio = $\frac{X}{Y}$

Y= Road amplitude, 50 mm considered

$\frac{X}{Y} = \sqrt{\frac{1+(2 \text{ x } \gamma \text{ x } r)^2}{((1-r^2)^2)+(2 \text{ x } \gamma \text{ x } r)^2}} = \frac{1.2126}{0.6199+0.2126} = 1.4565$

X = 1.4565 * 0.05= 72.8 mm

3. SOFTWARE SOLUTIONS

Concept 1: Suspension System with Single Helical Coil

In this concept we will design a suspension system with single helical coil. We will study the deflection and load absorbing characteristics of the system. We will apply static load to the suspension and will continue with varying loads.

Figure 1: Section View of the Spring Only Mono Suspension

Loading and Boundary Conditions for the static analysis

Loading and boundary conditions are given as per actual scenario. Apart from the total loading condition considered from the vehicle side i.e. 200 Kg, 250 Kg and 300 Kg some other loading also considered. All loading details are explained in this section.

3D Stress and deformation analysis of the suspension system with 200 Kg force

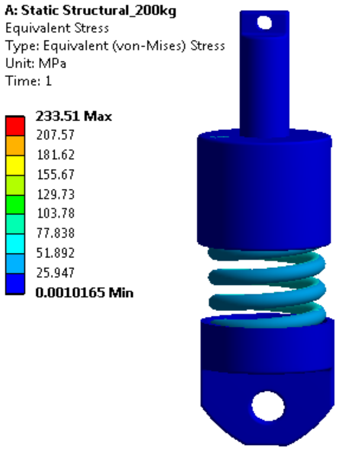


Figure 2: Equivalent Stress of the Concept 1

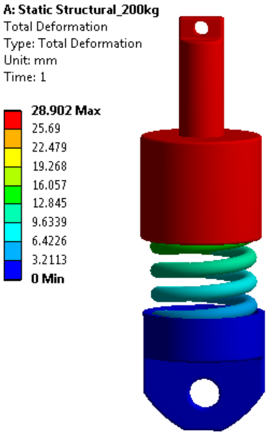


Figure 3: Deformation of the Concept 1

There is a max deformation of 28.9 mm is found in the model and equivalent stress of 233.51 mm is found at 200 Kg load analysis.

250 Kg load has been applied to the spring suspension system. Maximum stress of 291.89 MPa is found in the system and 38.53 mm deflection is recorded during the simulation.

300 Kg load has been applied to the spring suspension system. In the stress analysis maximum stress of 379.46 MPa is found at the system and 48.17 mm deflection is recorded.

Dynamic Response combined graph for 200Kg, 250Kg and 300Kg

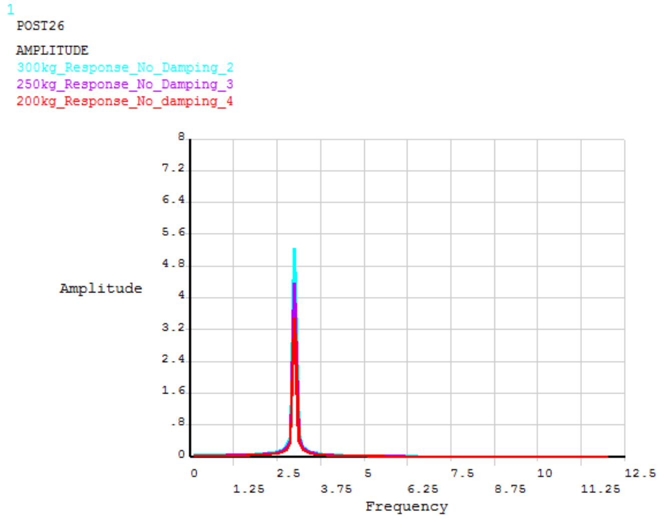


Figure 4: Combined Graph of Undammed Response of the Spring only Suspension

Dynamic analysis of the 300 Kg spring only suspension will get fail under above loads. There is amplitude of 5 m which is very high and is an indication of clear failure.

So with the help of sinusoidal loading it is concluded that spring only suspension is incapable in handling the dynamic loads. So it is mandatory to include proper damper system along with spring. So in further study hydraulic dampers are added along with spring.

Concept 2: Analysis with Spring with Hydraulic Damper

Spring the only suspension system failed with the application of dynamic load. So introducing proper dampers is necessary in the suspension system. We introduced hydraulic damper along with the spring. Hydraulic damper is added strategically to counter dynamic loads and provide a smooth ride.

Concept 2 Design

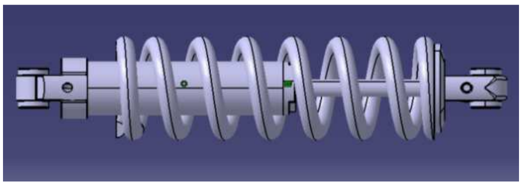


Figure 5: Concept 2 Front View in Horizontal Position

3D Static Stress Analysis with 200Kg

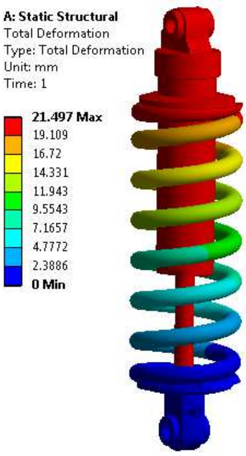


Figure 6: Deformation of 200 Kg, Concept 2

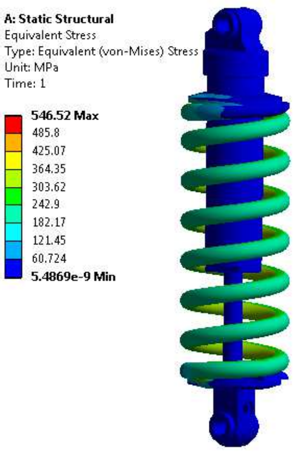


Figure 7: Stress in 200 Kg, Concept 2

3D model static stress study has been done for the suspension model. Maximum deformation of 21.497 mm is found in the model and equivalent stress of 546.52 MPa is recorded in the system.

250 Kg static stress study has been done for the concept 2 suspension model. Maximum stress of 601.17 MPa and deformation of 23.647 mm is found in the suspension system.

The static stress of the suspension system is done for 300 Kg load. Maximum stress of 683.15 MPa is found at the suspension system and deformation of 29.01 mm is recorded.

Dynamic Response combined graph for 200Kg, 250Kg and 300Kg

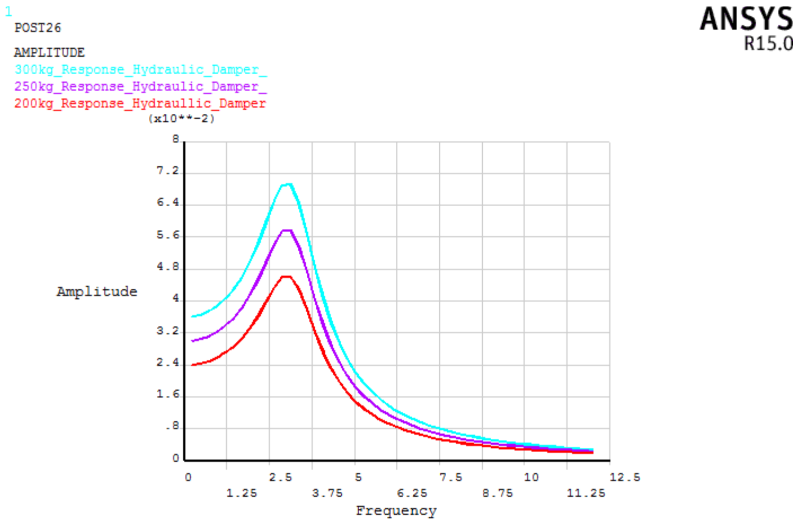


Figure 8: Combined Response Concept 2

In this graph it is clearly visible that at 300 Kg force with 0.6 damping ratio maximum amplitude of 6.6mm is found in the system. At 250 Kg, 5.65 mm and at 200 Kg 4.6 mm is recorded. Comparing with the concept 1, concept 2 is better with dynamic load.

So in the next step concept 3 is developed from the continuing concept 2 in which extra damping will be added with other techniques.

Concept 3: Analysis with spring with combined Hydraulic and Pneumatic Damper

In hydraulic dampers it is validated that, it is better than the spring only suspension system. By adding hydraulic dampers to the suspension system behaving good to the dynamic loads and deflection under sinusoidal load is well controlled. Up to 60% damping achieved through the hydraulic dampers.

In the 3rd concept we are adding accumulator to the hydraulic damping system. This accumulator is reservoir for any neutral gas (example Nitrogen) and will provide cushioning for the hydraulic damping system. This will combine the mono suspension system with spring, hydraulic and accumulator with gas as fluid.

The model for the concept 3 is shown below

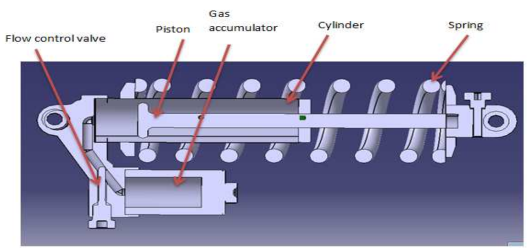


Figure 9: Cut Section of the Concept 3

3D Static Stress Analysis with 200 Kg Load

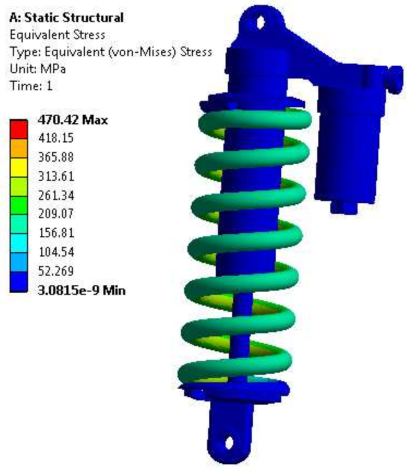


Figure 10: Stress, Concept 3- 200 Kg

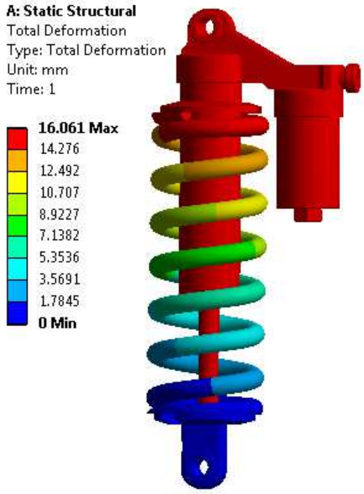


Figure 11: Deformation Concept 3 for 200 Kg

3D model static stress study has been done for the suspension model. Maximum deformation of 16.061 mm is found in the model and equivalent stress of 470.42 MPa is recorded in the system.

3D model static stress study has been done for the suspension model with 250Kg. Maximum deformation of 21.41 mm is found in the model and equivalent stress of 529.22 MPa is recorded in the system.

3D model static stress study has been done for the suspension model with 300Kg. Maximum deformation of 26.768 mm is found in the model and equivalent stress of 588.02 MPa is recorded in the system.

Dynamic Response combined graph for 200Kg, 250Kg and 300Kg

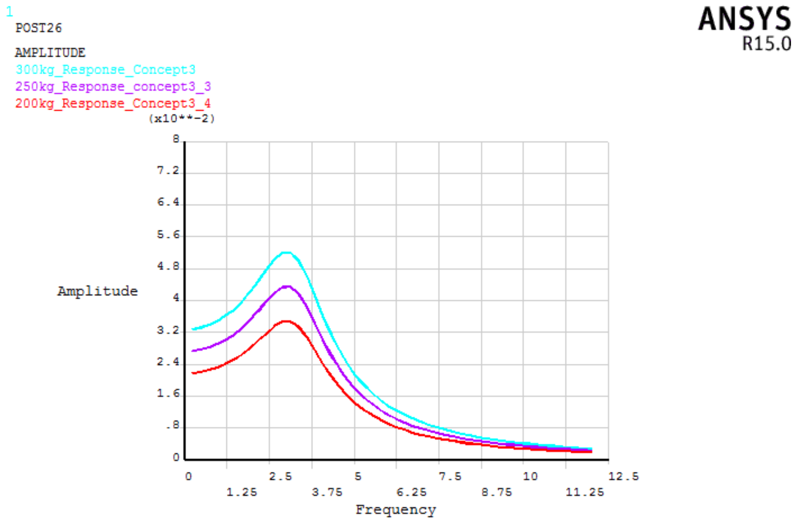


Figure 12: Combined Response Concept 3

In this graph it is clearly visible that at 300 Kg force maximum amplitude of 5.1mm is found in the system. At 250 Kg, 4.4 mm and at 200 Kg 3.3 mm is recorded.

4. RESULTS AND DISCUSSIONS

So from the analytical test section 50 mm of bump from the road will be transmitted to the vehicle at 72.8 mm. The amplitude and natural frequency results are tabulated below.

Table 7: Spring Suspension Amplitude Table

Weight Kg	Speed, Km/Hr.	Natural Frequency Rad/sec	Amplitude of Vehicle, mm
200	5	18.92	72.8
	40	18.92	4.25
	60	18.92	9.33
250	5	16.927	62.7
	40	16.927	12.275
	60	16.927	8.285
300	5	15.45	64.705
	40	15.45	2.69
	60	15.45	1.1265

In the first case we designed helical spring, which can take practical loads. These loads are 200 Kg, 250 Kg and 300 Kg. Helical spring concept design for our loading condition is designed and static and dynamic simulation is done. CATIA 3D modelling software is used in the CAD model design and detailing work. ANSYS FEA software is used to simulate static and dynamic analysis.

In the static condition, there is a maximum deflection of 27.9 mm for 200 Kg, 34.9mm for 250Kg and 41.8 mm deflection for 300 Kg load application. Static case is an initial stage for any analysis. The deflection results are accepted as our maximum travel distance of the suspension system is 75 mm. Hence the 2nd stage dynamic analysis is carried out for the spring only mono suspension.

At 50 mm road amplitude there is a dynamic response of 3.2 m which clearly indicates the failure of the spring only suspension. The maximum allowed amplitude for the suspension is 75mm in our case. Same way for 250 Kg, 300 Kg

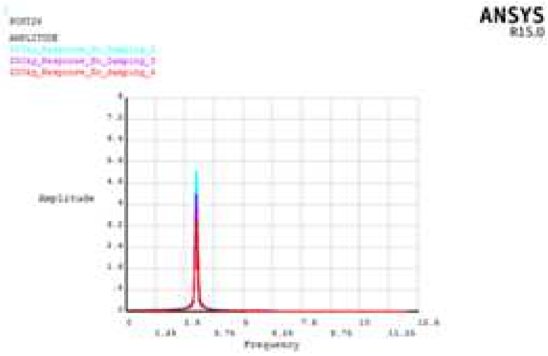
spring only suspension dynamic response is found with harmonic analysis and result is complete failure of the suspension which is not at all accepted. Hence (concept 2) adding a proper damper to the same spring only mono suspension is carried out.

In spring with hydraulic damper we directly calculated dynamic response because same helical spring is tested under static condition which shoed accepted deflection values. So at 200 Kg, 250 Kg and 300Kg dynamic simulation are carried out in ANSYS. We achieved at 300 Kg force with 0.6 damping ratio maximum amplitude of 6.6mm is found in the system. At 250 Kg, 5.65 mm and at 200 Kg 4.6 mm is recorded. Compared to the spring only suspension these values are very much acceptable.

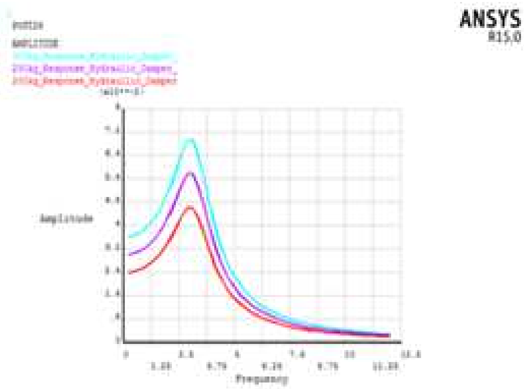
But our goal was to achieve at least 80% of damping characteristics of the system, and achieved damping is only 60%, hence this design is further modified and concept 3 done.

After combining the response curve of the concept 3 it is clearly indicates there is an improved damping properties in the mono suspension system. Its behavior is better compared with concept 2 hydraulic damping system. With the help of the combined hydraulic and pneumatic dampers (accumulator) we achieved 80% of the total damping.

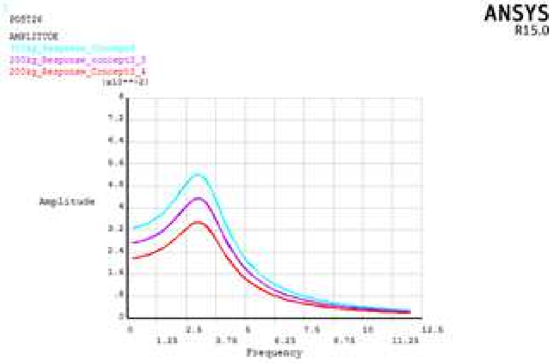
5. CONCLUSIONS



Concept 1



Concept 2



Concept 3

Figure 13: Dynamic Response of all Three Concepts

Thus the mono suspension improves the ride quality and helps in efficient handling of the vehicle.

It helps to absorb impact load caused by irregularities of the road surface.

It also provides comfort and reduces the fatigue cause to the rider.

The concept 3 is shown better results compared to the other earlier concept in damping properties.

So under considered loading condition concept 3 suspension system with spring, hydraulic damper and gas accumulator satisfies the our design goal and hence will be proposed for the practical application purpose.

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